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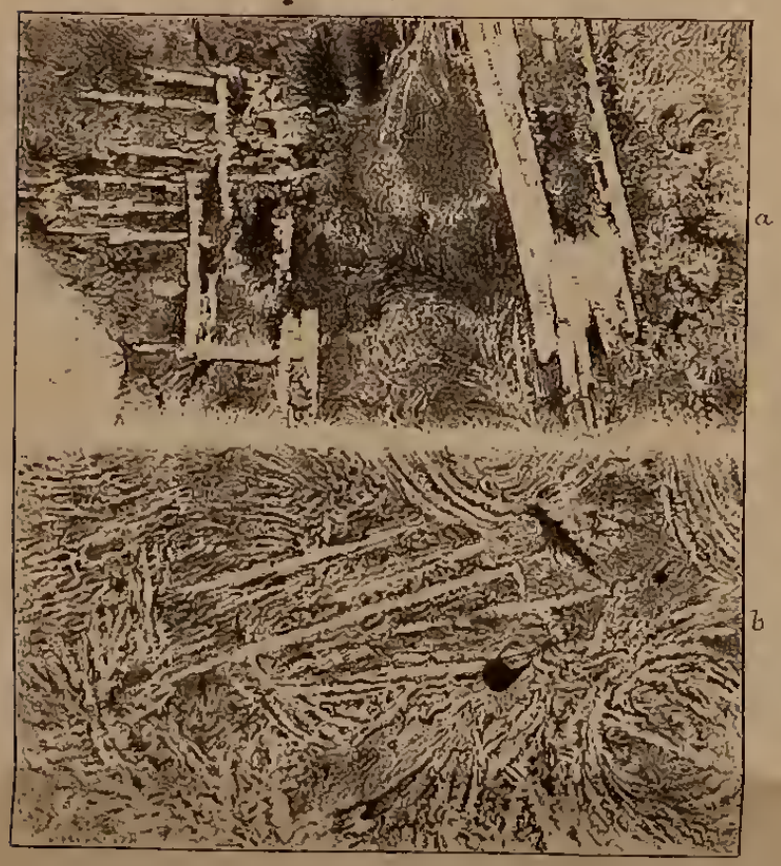

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W. n Wesley lith.

Nicol Newman & Co imp.

ROCKS OF NORTH-OF-ENGLAND DYKES.

H. M. Teall del.

J. W. Watson. del. et lith.

ROCKS OF NORTH OF ENGLAND DYKES

Watson & Son, lith., 33, Ct. Charles St. Birm.m

13. Petrological Notes *on some* North-of-England Dykes. By J. J. H. Teall, Esq., M.A., F.G.S. (Read December 19, 1883.)

[Plates XII. & XIII.]

The object of the present paper is to give a petrological account of some North-of-England dykes. The specimens on which the observations are based were mostly collected by myself during the winter of 1881–82; a few, however, were given me by Prof. Lebour and other friends.

In the microscopic work I have derived great assistance from my friends Mr. I'Anson of Darlington and Dr. Trechmann of Hartlepool. To Mr. I'Anson I am indebted in another way; for he kindly handed over to me the analysis of the Great Ayton rock which was prepared for him by Mr. Stock. My indebtedness to the latter gentleman, and also to Mr. Stead of Middlesborough, will appear in the sequel. Without the valuable chemical work communicated by these gentlemen my paper would indeed be incomplete. It is no part of my purpose to describe the mode of occurrence of these dykes, and therefore the general course of each is indicated mainly by reference to works already published. One or two new facts of importance are, however, given; especially in relation to the dying-out of dykes beneath the surface.

The dykes are first of all described in the order of their occurrence from south to north, and at the conclusion of the paper some general remarks on their mutual relations are given.

The Cleveland, Cockfield, and Armathwaite Dyke.

Literature.

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——. "On the Phenomena connected with some Trap Dykes in Yorkshire and Durham," Trans. Cambr. Phil. Soc. vol. ii. pp. 21–40.

Winch, N. J. "Observations on the Geology of Northumberland and Durham," Trans. Geol. Soc. 2nd series, vol. iv.

Phillips, John. Illustrations of the Geology of Yorkshire. Part i. 1st edit. 1829, 3rd edit. 1875, 190.

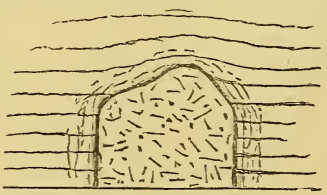
Tate & Blake. Yorkshire Lias, 1876, p. 210.

Handbook to Middlesborough and District, 1881, p. 50.

This dyke crosses the following one-inch Ordnance Maps: 95 N.W.; 96 N.E.; 104 S.W.; 103 S.E. and S.W.; 102 S.E., N.E., and N.W.

Before proceeding to describe the petrological characters of this remarkable dyke, it will be necessary to give some account of its mode of occurrence; this account will be compiled mainly from the works cited above. The most easterly exposure is near Maybecks on Sneaton High Moor, about six miles south of Whitby. From this point it may be traced, with occasional interruptions, in a W.N.W. direction by Silhowe Cross, Egton Bridge, Ainthorpe, Castleton, Commondale, Kildale, Eastby Moor, Rye-hill, and Ayton to Nunthorpe in the vale of Cleveland. At Maybecks it is 18 ft.* in thickness and at Silhowe Cross, 30 ft. At Great Ayton it is 80 ft.† thick at the base and 20 ft. at the top, which is 350 ft. higher. Throughout that portion of its course described above, a distance of over 20 miles, it is intrusive in Oolite and Lias, and the adjacent rocks are in many cases much altered. At many parts of its course the dyke forms a conspicuous feature in the landscape, as, for instance, on the Moors east of Silhowe Cross ‡, and at Cliff Ridge near Ayton. West of Nunthorpe it may be traced by Stainton and Preston to Coatham Beck, near the village of Elton, in the county of Durham. Between Nunthorpe and Stainton it is shifted about half a mile to the south; and at Preston it makes an abrupt bend at right angles to its usual direction. West of Cotham there is no exposure until we reach a point about a mile east of the village of Bolam (Ordnance Map 103 S.W.). In this interval the Magnesian Limestone occurs, so that the dyke is nowhere seen in contact with that formation. From Bolam it may be traced by means of surface outcrops and colliery workings to Cockfield Fell. Near the village of Bolam it expands laterally in the form of a "sill" or bed which is approximately parallel with the stratification, and attains a width of 200 or 300 yards. Mr. Howell, now Director of the Geological Survey of Scotland, was kind enough to conduct me to the various exposures in the neighbourhood of Bolam and Cockfield; and it may be interesting to place on record one or two of the facts which we observed. At the time of our visit (Jan. 1882) three quarries were being worked in the neighbourhood of Cockfield; and in the most easterly of these we saw a phenomenon which must be

Fig. 1.—*Dying-out of Dyke in Quarry near Cockfield.*



* 'Yorkshire Lias,' Tate & Blake, p. 210.
† Middlesborough Handbook, p. 50.
‡ Illustrations of the Geology of Yorkshire, 3rd ed. p. 191.

of frequent occurrence, but which cannot very often be directly observed, viz. the vertical dying-out of the dyke beneath the stratified rocks. The whinstone was seen to terminate upwards very abruptly in the form of a low and somewhat irregular dome, over which the coal-measure shales passed without any fracture and only with a slight upward arching (fig. 1).

West of this face and for a distance of about half a mile the dyke has been quarried, and its course is therefore marked by a deep trench. At one point it has been shifted laterally by a fault a little more than its own thickness. The next working-face is the largest one in the district. The width of the dyke at the time of our visit was 66 ft., and the depth of the working-face about 40 or 50 feet. Here the dyke was quite vertical.

In the next quarry to the west, the width of the entrance was about 15 feet, and at the working-face, 170 yards further east, 29 feet. Here the dyke hades to the S.S.W. at an angle of 70°. The adjacent rocks are shales and sandstones, and the zone of alteration extends to a distance of 20 or 30 yards. At the north side of the main dyke, near the entrance to this quarry, is a narrow dyke, about 4 feet wide, of similar material.

West of this point the dyke does not appear at the surface for some distance; but Mr. Howell informed me that it has been proved in colliery workings; and there can be no doubt that the dyke crossing Woodland Fell in an east-and-west direction, which can be traced to a point about 1 mile east of Middleton, is the same one.

The above facts prove that the dyke in question varies very much in thickness both in a vertical and in a horizontal direction, that it frequently dies out before reaching the surface, and that it is liable to lateral shifts. Absence of continuity in the outcrop is thus seen to be no proof of a want of continuity underground.

Until quite recently it has never been suspected that this remarkable dyke could be traced any further to the west than the neighbourhood of Middleton. The work of the Survey, however, has rendered it almost certain that the well-known dyke in the Eden valley, extending at intervals from the neighbourhood of Renwick to Armathwaite, is a portion of the same igneous outburst.

Between the most easterly exposure of the Eden-valley dyke and the most westerly exposure of the Cockfield dyke, near Middleton, no less than nine exposures, all lying very much in the same general direction, are now known. Mr. Howell was kind enough to mark these exposures on my maps, and I was thus enabled to visit two of them—one about $1\frac{1}{2}$ mile north-east of High Force Inn, where the dyke crosses the Bowles Beck, at the junction of two streams, and another about one mile south of Tyne Head, where it is also seen crossing a stream. In both these exposures the rock presents the macroscopic and microscopic peculiarities about to be described.

From Bolam to the edge of the escarpment overlooking the Eden valley the dyke is intrusive in the various members of the Carboniferous formation. In the Eden valley it enters once more on Secondary ground. It has been traced by Renwick and Ruckcroft

to Armathwaite, where it crosses the Eden at the weir about half a mile above the bridge. There are many good exposures in the neighbourhood of Armathwaite. Its thickness in the railway-cutting is about 18 yards.

It thus appears that a dyke having characters which are constant and at the same time different from those of any other igneous rock known to me in the north of England may be traced at intervals from Maybecks in the east to Armathwaite in the west, a distance of about 90 miles; that it keeps on the whole a general W.N.W. direction but is liable here and there to lateral shifts and local deviations; and that it may be seen in one place, and proved by colliery workings in others, to die out before reaching the surface; so that in districts where it is not actually seen it may reasonably be supposed to exist underground.

Doubts have been expressed as to the continuity of the Cockfield and Cleveland dykes. When, however, we see that the petrological characters of these two dykes are not only alike, as has been remarked by Prof. Sedgwick and others, but also peculiar, a point which is, I believe, now insisted upon for the first time, there can, I think, be no longer any hesitation in admitting their continuity, especially as they follow each other very much in the same straight line. And if we admit the continuity of the Cleveland and Cockfield dykes, we are compelled by the same kind of evidence to regard the Armathwaite dyke as a portion of the same igneous outburst.

What is the age of this dyke? The latest formations intersected and altered by it are the oolitic sandstones of the Yorkshire moors. It must therefore be post-Jurassic. The only period subsequent to the Jurassic in which volcanic action is known to have taken place in Western Europe is the Tertiary, and especially the Miocene; and inasmuch as the dyke in question points by its direction to the north of Ireland, and west of Scotland, districts celebrated for the enormous development of Miocene volcanic rocks, we seem compelled to regard it as of Miocene age.

It has been suggested by some that there may be a connexion between the Great Whinsill of Teesdale and the dyke in question. This seems to me in the highest degree improbable. There are marked chemical and physical differences between the two rocks, even where, as at Tyne Head, they occur in close proximity, and where the Cockfield Dyke has in all probability cut through the Whinsill. The Whinsill is composed of a rock of more basic composition and higher specific gravity than that of the dyke. It is moreover holocrystalline, whereas the dyke contains a considerable amount of imperfectly individualized matter. It is interesting to note that the Whinsill is similar in composition, structure, and mode of occurrence to the diabase (? dolerite) which is so extensively developed in the Triassico-Jurassic strata of Nova Scotia, Massachusetts, Connecticut, New Jersey*, Pennsylvania, and North Carolina, and which possesses throughout the whole of its enormous range,

* See E. S. Dana, 'American Journal of Science,' 1874, ser. 3, vol. viii. p. 390, and G. W. Hawes in the same Journal for 1875, vol. ix. p. 185.

that is for a distance of 1000 miles, the same composition and structure. In a future paper I hope to give an account of the Whinsill, when these points will be more fully discussed.

I now proceed to describe the rock of the Cleveland, Cockfield, and Armathwaite dyke. The facts recorded are based on the observation of numerous specimens collected by myself at Ayton, Preston, Bolam, Cockfield, Bowles Beck, Tyne Head, and Armathwaite. Many sections* have been prepared of the rocks from each of these localities, and several chemical analyses have been placed at my disposal by my friends Messrs. Stead and Stock. I have also made a large series of specific-gravity determinations. All these observations prove the essential uniformity of the rock along the whole line of outcrop.

Petrology of the Cockfield and Armathwaite Dyke.

The rock is usually of a dark grey or bluish grey colour when freshly broken, but it becomes darker after exposure to the air. It is porphyritic in texture, and frequently, though not invariably, possesses a subconchoidal fracture. The porphyritic crystals are glassy-looking felspars, which occasionally show on their cleavage-faces the striations due to repeated twinning. The crystals are sometimes whole, sometimes fragmentary, the fragmentary condition evidently indicating that they were not developed where we now see them. Sections more or less parallel to the basal plane are usually long in proportion to their width; whereas those which are parallel to the brachypinakoid have tolerably uniform dimensions in the different directions. These facts doubtless show that the crystals are less developed in the direction of the macro-diagonal than in the directions of the other two crystal axes. The sections, when measured across, vary from 1 mm. to 5 mm. These porphyritic crystals are distributed throughout the ground-mass with considerable regularity along the whole length of the dyke. Three or four conspicuous ones usually occur on a square inch of surface, thus giving the rock of this dyke a definite macroscopic character, by means of which it can be distinguished from that of any other dyke known to me in the north of England. The ground-mass varies according as the specimen is taken from the margin or from the centre of the dyke. At the margin and for a few inches inwards it appears to the unaided eye compact and homogeneous, and the large porphyritic crystals, which are just as well developed here as in the centre, stand out very conspicuously; beyond this, however, it becomes finely and, in a few cases, where the dyke is thick, even coarsely crystalline.

The rock, especially at the margins of the dyke, frequently effervesces freely with hydrochloric acid; this indicates the development of carbonates by secondary processes, and marks the first stage of decomposition. A further stage may be well seen at the

* I have had 27 sections prepared from my own specimens, and several others have been placed at my disposal by my friends Messrs. I'Anson and Trechmann.

north margin of the dyke, in the large quarry at Cockfield, and at the base of the intrusive sheet at Bolam. In the former locality the actual margin consists of a brown layer about an inch in thickness, and evidently rich in iron oxides. This is sharply divided from a light grey band in which kaolinized felspars are very conspicuous. This band is several inches in thickness and shades off gradually into the main mass of the dyke. It does not effervesce with acid; but the dark and, to the eye, comparatively unaltered-looking rock which adjoins it does effervesce. Carbonates are thus seen to be present in the dark rock, but absent in the light-grey band, which therefore represents a further stage of decomposition. My friend Mr. G. E. Stead, of Middlesboro', to whose kindness and generosity I am indebted for most of the analyses which appear in this paper, found the white substance occurring beneath the whin at Bolam to contain:—

	Per cent.
Silica	54·00
Alumina	30·93
Iron oxides	0·78
Lime	0·47
Magnesia	0·74
Potash	1·11
Soda	2·75
Loss	8·95
	99·73

It is thus seen to consist mainly of hydrated silicate of alumina, and to have been formed from the original rock (see analysis on p. 224) by the removal, doubtless as carbonates, of the iron, lime, and magnesia. It appears remarkable that the alkalies should have been left. Now the light-grey band at Cockfield is evidently similar in composition to this white substance, although probably the removal of lime, iron, and magnesia has not been quite so effectually carried out. The brown band which forms the actual margin is certainly rich in iron-oxides, so that there appears to have been here as at High Green (see p. 240) a removal of the iron from the interior of the rock and a concentration of it along a bounding surface.

Narrow veins of calcite may occasionally be seen traversing the rock, and these sometimes contain pyrites. Dr. Veitch, of Middlesboro', gave me a specimen of the rock showing a joint surface coated with a radiating fibrous zeolite, which Dr. Trechmann determined to be pectolite.

Angular and subangular portions, which appear homogeneous to the unaided eye, are frequently seen lying in a finely crystalline ground-mass. As these fragments resemble very closely the rock formed by rapid consolidation at the sides of the dyke, I am disposed to regard them as having been portions of the side which were broken up and carried along by subsequent movements of the igneous matter. Inclusions of foreign rocks are not common. The only specimen which has come under my notice was found by Dr. Trech-

mann among the road-metal at Hartlepool; it is an angular fragment of what is now a light-grey quartzite. The sharpness of the angles of this specimen appears remarkable when one takes into consideration the evidence of extreme metamorphism which the microscope affords.

The inclusion, as a whole, is now composed of extremely irregular grains of crystalline quartz, which fit together so as to leave no interspaces. Here and there, however, more or less oval spaces occupied by the magma of the igneous rock may be recognized, and in much of the quartz secondary glass inclusions similar to those described by Chrustschoff* and Dölter† occur.

The other macroscopically recognizable constituents are blebs of quartz (Ayton, Preston, and Cockfield), small agates, usually associated with calcite (Bowles Beck), and irregular patches of pyrites. These, however, are not uniformly present, but occur rather as local peculiarities.

I have made 23 specific-gravity determinations on specimens taken from widely separated localities, including Great Ayton, Preston, Bolam, Cockfield, Bowles Beck, Tyne Head, and Armathwaite, with this general result that, when care is taken to select unaltered or but slightly altered specimens, the specific gravity is found to lie between 2·765 and 2·788. The best observations indicate 2·77 as the mean. Altered specimens have a lower specific gravity: thus two from Cockfield and Tyne Head respectively gave 2·63 and 2·62.

The microscopic as well as the macroscopic characters are remarkably constant along the whole length of the dyke, so that in describing the rock from a microscopic point of view it will not be necessary, except in a few special cases, to refer to separate localities. Two important structural types may be observed; the one characteristic of the main mass of the dyke, the other of the few inches which form the margin. These will be referred to again when the separate constituents have been described.

The original constituents may be considered under the following heads:—(*a*) porphyritic felspars, (*b*) felspars of the ground-mass, (*c*) augite, (*d*) magnetite and ilmenite (?), (*e*) biotite, (*f*) apatite, (*g*) interstitial matter with globulites, longulites, microlites, &c.

The two varieties of felspar will be referred to simply as the large and small felspars; they belong, of course, on the whole to two different stages in the process of consolidation, although it is probable that the outer zone of the large felspars was frequently added during the formation of the felspars of the ground-mass. Biotite occurs sparingly, and has only been observed in certain sections from Ayton and in one from Armathwaite. Apatite does not seem to be abundant; indeed its presence is inferred rather from the chemical than from the microscopic analysis. By interstitial matter is meant

* Chrustschoff, "Ueber secundäre Glaseinschlüsse in den Gemengtheilen gefritteter Gesteine," Tschermak, Min. u. petr. Mitth. 1882. Neue Folge iv. p. 473.

† Dölter and Hussak, "Ueber die Einwirkung geschmolzener Magmen auf verschiedene Mineralien," Neues Jahrbuch, 1884. Bd. i. p. 18.

that portion of the rock which cannot be resolved into distinct crystals or crystalline grains by the aid of the microscope; it may be glassy, micro-felsitic (Rosenbusch), crypto- or even micro-crystalline. It usually gives a decided reaction with polarized light, a true glass having been distinctly recognized only in one instance, viz. in that of a specimen from Armathwaite. The secondary constituents comprise (*a*) quartz, (*b*) calcite, (*c*) chloritic alteration-products, (*d*) limonite, (*e*) pyrites. Some of the quartz may be original.

In order to form some notion of the relative importance of the different constituents of the ground-mass, I selected two fairly characteristic photographs, and, having cut out the portions representing the different constituents, weighed them separately. The following is the percentage composition of the rock as thus determined:—Augite and magnetite 11·4 per cent., small felspars 29·1 per cent., interstitial matter 59·5 per cent. It is difficult to cut out the parts exactly, so that a liberal margin for error must be allowed. It must also be remembered that the interstitial matter contains microlites of augite and felspar, which cannot be cut out and weighed separately. The magnetite was taken with the augite because it was found impossible to separate the two in the photograph; magnetite, however, forms only a very small proportion of the entire mass of the rock. The relative abundance of the different constituents is a fairly constant feature of this and also of the other dykes to be described; so that the application of this method, originally due to Dr. Sorby, I believe, becomes of considerable importance.

Large Felspars.—These occur, as already stated, in a tolerably constant proportion, and give the rock of this dyke a macroscopic character which enables one to recognize it at once wherever it occurs. Sections more or less parallel to the brachypinakoid appear as large flat plates, having tolerably equal dimensions in the different directions, and polarize in a uniform tint, or else show striations due to twinning on what may be assumed to be the pericline type. This twinning is very irregular as regards the length and breadth of the lamellæ. Sections out of the zone of the brachydiagonal axis are frequently much longer than broad, and they show the striation due to twinning on the albite plan. This twinning is also irregular so far as the width of the bands is concerned. Sometimes the section is divided into two well-marked halves: but when this is the case each half usually contains a few very narrow bands which extinguish simultaneously with the other half, thus showing that the crystals are twinned on the albite and not on the Carlsbad plan, as might at first sight be supposed. The large felspars are frequently in the condition of fragments; and sometimes a crystal may be seen to be fractured and to have had its parts slightly displaced, but not actually separated from one another. The fragmentary state of many of the large felspars, as also the fact that they occur in the same condition at the sides and in the centre of the dyke, proves that they have not been formed *in situ*, but have been brought into their present position from below.

It is difficult to obtain cleavage-flakes of these felspars for optical

examination; but after many failures I have succeeded in preparing one reliable slide. The section is approximately at right angles to the twinning-plane and parallel to the edge $o\,P \mid \infty \breve{P}\infty$. Two separate determinations of the extinction-angles of adjacent lamellæ, with reference to the trace of the twinning-plane, gave (*a*) 5° 10′ and 7° 20′, (*b*) 5° 35′ and 7° 10′. This shows that the section is not exactly perpendicular to the twinning-plane, because if it were, the extinctions would be symmetrical; nevertheless it may be regarded as sufficiently near for the purpose of comparison with the table given by Messrs. Lévy and Fouqué ('Minéralogie Micrographique,' p. 230). We find on referring to that table that in labradorite the extinction-positions of adjacent lamellæ in the plane passing through the edge $o\,P \mid \infty \breve{P}\infty$, and normal to the twinning-plane, lies between 10° and 14° 30′, and differs markedly from the corresponding angle in the other well-defined species of felspar. In the case in question it may be taken as about 12° or 13°, and we are therefore led to the conclusion that the felspar is labradorite. It is perhaps hardly safe to infer that all the large felspars belong to the same species; indeed the results obtained by observing the angle between the extinction-positions of adjacent lamellæ in the felspars exposed in the rock-sections seem to indicate the presence of a felspar more nearly allied to anorthite. The large felspars contain inlets and inclusions of the ground-mass, and frequently show the most exquisite zonal banding (see Pl. XII. fig. 3). In one typical case which is now before me this banding is due to brownish, more or less spherical or elliptical, granules, which vary in size from the smallest specks visible with a magnifiying power of 270 diameters up to those which measure ·02 mm. × ·01 mm. The larger granules are markedly elliptical, and their longer axes are set parallel to the longer edge of the crystal section. They keep this parallelism throughout the zone, a fact which shows that the elliptical form was determined by the unequal rate of growth of the crystal in different directions. There are also larger irregular inclusions which do not lie in definite zones. It is worthy of note that the distance between contiguous zones is greater in the direction of the length than in that of the breadth of the crystal section; another fact indicative of the unequal rate of growth of the crystal. Sometimes the large felspars are completely honey-combed by irregular ramifiying inclusions; at other times the centre only contains such inclusions. Not unfrequently they are surrounded by a narrow outer zone, which extinguishes at a slightly different angle from the rest of the section. Thus, in one case in which the extinction-angles of the main mass of the crystal were 30° 35′ and 33° 20′ on either side of the twinning-line, those of the outer zone were some 3° or 4° greater on either side. If we assume* that this difference is due to difference in composition, and that the optical properties are related

* In 'Comptes Rendus' for 23 Jan., 1882, M. Lévy points out that the variations in the angles of extinction in successive zones need not necessarily indicate variations in chemical composition. His mathematical investigations

to the chemical properties in the manner laid down by Schuster (Min. Mitth. 1881, p. 117), then it indicates that the outer portion of the crystal approaches more closely to the composition of anorthite than that which forms the main mass. It is worthy of note that in this crystal, as in most of, if not all, the others which show the same character, although the outer angles are tolerably sharp, those of the internal portion (the nucleus, as it may be termed) are more or less rounded. In another section three zones may be recognized; the outer and inner ones extinguish simultaneously, but the middle one extinguishes at an angle which shows a nearer approach to anorthite. The outer edges of crystals zoned in this particular manner are frequently ragged owing to inlets of the ground-mass; these inlets, however, are limited to the outer zone and do not penetrate the central portion. It is clear therefore that the outer zone was added during one of the later stages in the process of rock-consolidation, and probably after some of the constituents of the ground-mass had separated out.

Small Felspars.—These vary in character according as the section is taken from the main mass or from the margins of the dyke. In the latter case they consist for the most part of small microlites, whereas in the former they may be (*a*) fairly well developed crystals, not very long in proportion to their width, (*b*) imperfectly developed and skeleton crystals, (*c*) long narrow acicular microlites. The more perfectly developed crystals are frequently ragged at their extremities, and sometimes run out into the long narrow microlites, thus proving the felspathic nature of the latter. The sections of the more perfect crystals are often lath-shaped in form, and usually lie between the following dimensions:—× ·1 mm. × ·35 mm. and ·2 mm. × ·5 mm. The small felspars are distinguished from those which give the rock its porphyritic character by the general absence of inclusions, and of zonal banding, as well as by their size. They occasionally show the repeated twinning characteristic of plagioclase, but more frequently occur as binary twins and simple individuals. The following numbers represent a series of measurements of the extinction-positions of adjacent lamellæ, with reference to the twinning-line, those crystals being selected which gave approximately symmetrical extinctions: 21° and 34°, 22° and 35°, 26° and 29°, 33° and 28°, 21° and 19°. Another series of observations in which the angle between the extinction-positions of adjacent lamellæ alone was recorded, gave 27°, 19°, 6°, 58°, 36°, 46°, 22°, 41°, 44°, 47°. It thus appears that 58° was the maximum observed. The maximum for labradorite in the zone which gives symmetrical extinctions with reference to the twinning-line is 62° 30′, that for oligoclase 37°, for albite 31° 30′, and for anorthite over 74° 42′. The measurements therefore appear to indicate the presence of labradorite, but they can of course tell us nothing as to the presence

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lead him to the conclusion that they may be accounted for, in certain cases, on the assumption that the crystals are built up by the association of submicroscopic twin lamellæ.

or absence of oligoclase or albite. The researches of M. Fouqué on the mineralogical composition of the Santorin augite-andesite lava of 1866, led him to the conclusion that the porphyritic felspars of that rock were mainly labradorite, but that they comprised also anorthite, sanidine, and oligoclase, and that the felspars of the ground-mass were albite and oligoclase. It is highly probable that the rock we are considering, which appears to be a fairly typical augite-andesite, though not so rich in silica as the lava of Santorin, also contains a mixture of different felspars.

In the description of the remaining felspathic constituents of the ground-mass it will be convenient to begin with the microlites. These may be either straight or curved. The majority of them lie between the following dimensions:—width ·002m. to ·004 mm.; length ·06 mm. to ·35 mm. As a rule, these microlites are not sharply defined from the interstitial matter; thus, the interstitial matter of the rock which occurs at the old quarry at Barwick, on the right bank of the Tees, near Preston, shows under a high power (270 diameters) a sort of mottled appearance due to the irregular interlacing of darker and lighter portions. In places these lighter portions assume a linear form, and take on the characters of the microlites (see Pl. XII. fig. 4 *b*). Curved microlites are common in the same rock; they are sometimes clustered together so as to give rise to curious plume-like forms. The straight microlites extinguish in the direction of their length. The curved microlites have the same optical properties, and do not therefore extinguish simultaneously in any one position, only that portion of any particular microlite appearing dark which happens to lie parallel with one of the two vibration-planes. Not unfrequently the microlites show a tendency to unite with each other at definite angles; and this leads to the building-up of curious skeleton-like forms. The rectangular mode of junction is the most common. When the primary microlite is curved, then the secondary microlites converge like the spokes of a wheel.

The skeleton felspars (see Pl. XII. fig. 4 *a*) constitute an intermediate group between the microlites and the more or less perfect felspars, and they exhibit a very great diversity of form. Commencing with those which consist of a primary microlite to which secondary microlites have attached themselves at right angles, we may pass, by means of those which consist of two parallel microlites, joined, either at their centres or at their ends, by transverse microlites, to broad rectangular felspar sections, bounded by sharp straight edges, or else running out at their ends into acicular microlites. These skeleton forms are best studied in sections from the Barwick and Armathwaite quarries. I have observed somewhat similar forms in the dolerite of Sababurg, in Hesse, and in that of Dalmahoy Hill, near Edinburgh, also in some of the other dykes to be hereafter described. Bořický has described similar forms in the melaphyres of Bohemia (Petrographische Studien an den Melaphyrgesteinen Böhmens, p. 9, pl. i. fig. 7).

Augite.—This mineral, like the felspar, occurs in two conditions,

(1) as fairly large (·55 mm. × ·75 mm.), and more or less perfectly developed crystals of the common form; and (2) as minute crystals or crystalline granules (·05 mm.). The former show fairly good cleavages, which appear in the sections as lines running parallel to each other, or else belonging to two series which intersect at various angles according to the direction of the crystal section, up to about 90°. They are not numerous, but in the slides in my possession may be recognized the eight-sided, six-sided, and four-sided forms characteristic of sections more or less at right angles to the principal axis, parallel to the ortho-pinakoid, and parallel to the clino-pinakoid respectively. By far the larger portion of the augite occurs in the form of minute crystals and crystalline grains. A green chloritic substance, having a fibrous appearance in thin sections, sometimes wholly or partially replaces the augite. In some of the sections from the Barwick quarry the augite crystals are entirely replaced by calcite pseudomorphs, giving aggregate polarization. These are especially interesting, as the forms of the replaced augite were evidently very perfect. Augite does not, at any rate as a rule, occur as inclusions in the large porphyritic felspars. Many of the very small augite grains when examined with a magnifying power of 500 diameters, are seen to have their edges ill defined and ragged like the felspar microlites, and seem to be connected with the brownish substance which appears as indistinct granules and fibres in the interstitial matter. This very interesting feature will be again referred to in describing the microscopic character of the interstitial matter.

Magnetite (and Ilmenite?).—This occurs in the form of fairly well-developed crystals, and also as skeleton crystals and small granules. The crystals show the usual quadratic, triangular, and hexagonal forms. Now and then a lath-shaped section occurs, such as might be formed by cutting a tabular crystal of ilmenite at right angles to the basal plane. The occurrence of this latter mineral must, however, be regarded as doubtful; for the microscopic evidence is not clear, and the small quantity of titanic acid revealed by analysis may be contained in the magnetite. On heating a thin section for some time with hot hydrochloric acid, the black opaque mineral entirely disappears.

Biotite.—This mineral is not constantly present. It has been observed in specimens from Armathwaite and Ayton. It shows a tendency to alteration, and is frequently represented by green chloritic fibres.

Quartz.—This may be recognized in most of the slides, either in the form of definite crystals or as crytalline grains, which usually show a polysynthetic structure. It may, in part, be an original constituent; but from its frequent association with calcite, I am inclined to class it under the secondary minerals.

Calcite.—This mineral occurs in irregular crystalline plates, giving definite extinctions, and is also scattered throughout the slide in the condition of crystalline powder. The last-mentioned mode of occurrence indicates, however, a very advanced stage of

decomposition, and is usually found only in those slides in which the augites have been replaced by calcite. The irregular crystalline plates occur in comparatively unaltered rocks, and they are here seen to be almost invariably associated with quartz. Both quartz and calcite also occur in thin veins. Small spherical amygdules containing calcite and chalcedony occur in certain localities, and especially at Bowles Beck, where my attention was first called to them by Mr. James I'Anson.

Pyrites.—This mineral occurs abundantly in certain localities, but is not distributed throughout the rock with any definite regularity. It owes its origin, no doubt, to local causes. Under the microscope it appears as irregular ragged plates, the true nature of which can, of course, only be recognized by reflected light.

The Interstitial Matter.—This is in some respects the most interesting portion of the rock. It forms, as a rule, about one half of the ground-mass, and presents a number of remarkable structural variations. Although giving, in the majority of cases, a decided reaction under polarized light, it consists of a number of imperfectly individualized substances. In order to study the characters of this substance, it is absolutely necessary to have the thinnest possible sections and to use a magnifying power of not less than 500 diameters. We will consider first of all the case of a somewhat exceptional variety of the rock, which occurs at Armathwaite. The ultimate base is a clear isotropic glass containing a large number of extremely minute brownish granules. With a magnifying power of 500 diameters the smallest granules appear as mere specks, while the larger ones have frequently a globular or elliptical form. Clusters of granules may frequently be seen, and these appear to show a tendency to a linear arrangement, The granules are without action on polarized light. They belong to the *globulites* of Vogelsang (Die Krystalliten). In addition to the globulites, there are also long, more or less conical needles of the same substance. The thin ends of these needles are usually clear and transparent, and the external surfaces smooth; but the thick ends are rough, and evidently made up of globulites which have not entirely lost their individuality in the attempt to form these needle-like bodies. The bodies in question give no reaction with polarized light, and they correspond therefore with the *longulites* of Vogelsang. The smaller ends of the longulites rarely, if ever, lie free in the glassy base, but are in contact with minute augite granules, around which they are arranged in a rude kind of radial manner (see Pl. XII. fig. 2 *a*). In short the smaller augite grains may be described as bristling with longulites. It is worthy of note that the felspars of the ground-mass appear to have exercised no influence whatever on the grouping of the globulites and longulites.

The conical needles which occur in a slag figured by Vogelsang (Die Krystalliten, pl. ii.) are described by him as having been formed by a double process of growth, the pointed end having been produced by the coming together of the very smallest spherical elements ("die kleinsten constituirenden Kugelelemente"), and the

opposite or shank end by an aggregation of globulites. In the Armathwaite longulites it appears probable that the growth has always been in one direction, that is from the end in contact with the augite granule. At first the conditions were such that an intimate union of the constituent elements took place, and the smooth rod-like portion was produced. After a time, however, the conditions became more and more unfavourable to the individualization of distinct substances. Larger globulites were produced and brought together by the action of the attractive forces; but these did not become perfectly united, and thus the rough portion of the longulite was formed.

That the longulites are intimately connected with the globulites is proved by the occurrence of every possible kind of intermediate form. Thus one may pass from single globulites to a linear grouping due to the coming together of two or more globulites without actual union, and from this, again, to an elongated form which has evidently been produced by the union of distinct globulites at their points of contact. These, again, may be connected with the more perfectly developed longulites by intermediate forms. As will naturally be anticipated from the facts already described, the spaces surrounding the longulites are free from globulites; the material of the globulites has been abstracted for the purpose of forming the longulites. What substance is it whose crystallizing force has led to the formation of these non-crystalline bodies? It is impossible to demonstrate the fact, but I have little doubt that it is augite. A suspicion of this is aroused when one notices that the longulites cluster round the augite grains, which they resemble in colour and general appearance, but not round the felspars; and this suspicion is confirmed when one studies carefully the structure of some of the least perfectly developed augites. These have sometimes a fibrous look, and occasionally run out into microlites which cannot be distinguished from the longulites without the use of polarized light. I consider, therefore, that if we could isolate these globulites and longulites for separate analysis we should find them not to consist of pure augite substance, but of material richer in augite substance than the surrounding glassy base; just as in Vogelsang's experiments with sulphur and Canada balsam (Die Krystalliten, p. 8) the globulites and longulites consisted of Canada balsam containing more sulphur than the surrounding mass.

As a rule, the felspars of the ground-mass are entirely free from globulites and longulites. It does sometimes happen, however, that a portion of the base gives the reaction of felspar under polarized light, and at the same time contains these bodies.

We are thus led to the conclusion that the magma which remained fluid after the formation of the large felspars, the magnetite and many of the augite crystals and grains, still contained the chemical constituents of felspar and augite, and that the peculiar structures of the ground-mass owe their origin to the crystallizing power of these constituents acting under unfavourable circumstances. In short they may be regarded as the final attempts of these con-

stituents to assume a crystalline condition. Mr. Stock found (see his note, p. 225) that 35·57 per cent. of this rock remained insoluble after treatment with hydrochloric acid in a pressure-tube for one month, and that the insoluble residue yielded, on analysis, SiO_2 70·76 per cent.; Al_2O_3 10·93; Fe_2O_3 3·59; CaO 3·29; MgO 4·21; Alkalies 7·22. This may be taken as representing approximately the composition of the base with its various devitrification-products. It is, as one would naturally expect, highly acid; the silica here, as in other cases, having served as a sort of solvent medium out of which the other minerals have crystallized.

So far I have been referring to the prevailing type of interstitial matter in the Armathwaite slide. Here and there, however, in the same slide it puts on a very different aspect. It becomes deep brown in colour and is traversed by numerous ill-defined felspar microlites. The longulites and globulites are no longer to be recognized, and the whole patch gives a vague reaction on polarized light. This is the common type of devitrification, and may be well studied in sections taken from the rock which occurs at Barwick quarry, near Preston. Here the ill-defined felspar microlites occur in great abundance; but as they have already been described it will be unnecessary to refer to them at greater length. In the thinnest possible sections the brown colour is seen to be due to a kind of indistinct granulation which has evidently been produced by the imperfect individualization of a brownish substance. This substance appears as minute specks and ill-defined fibres. It is occasionally aggregated into irregular patches and narrow bands, which give the vivid polarization-tints characteristic of the small augite granules. I have not been able to recognize any clear transparent glass in the Preston slides; but some of the base containing indistinct fibres and granules appears isotropic, and may therefore be regarded as consisting of the micro-felsite of Rosenbusch. There is yet a third type of devitrification, also very common, which may be well studied in the specimens from Great Ayton. Indistinct granules, fibres, and ragged patches of a brownish substance which may be connected by intermediate forms with the augite granules, and which give the same reaction on polarized light, together with specks of opacite (? magnetite) lie intermixed with a substance which also reacts on polarized light. Thus, it splits up under crossed nicols into irregular patches of considerable size, which extinguish in definite positions, but whose boundaries are by no means well defined. Long, sharp, colourless microlites, and black hair-like bodies (trichites) may be observed in the base of the rock from certain localities.

Structural Variations of the Rock.—As already stated, only two well-marked structural types can be recognized, one characteristic of the main mass, the other of the margins of the dyke. They differ from each other merely in the extent to which crystalline growth has been carried in the ground-mass of the rock; for the porphyrite felspars are alike in both varieties. In the marginal part of the dyke the ground-mass is composed of minute felspar microlites

(see Plate XII. fig. 2), indistinct brownish granules (? augite), and specks of magnetite imbedded in a clear isotropic glass. In the rock from the central portions of the dyke the felspars of the ground-mass and augite grains are much more fully developed, and the base itself also appears completely devitrified. The rock from the margin of the dyke bears a striking general resemblance to many of the so-called augite-andesites of Hungary and Santorin.

Chemical Analyses of the Cockfield and Armathwaite Dyke.

	I.	II.	III.	IV.
Silica	57·57	58·07	59·25	56·10
Alumina	14·25	13·22	16·75	17·24
Ferric oxide	6·04	10·10	4·00	4·76
Ferrous oxide	3·95		4·82	
Manganese oxide	·27	...	...	...
Lime	6·87	7·04	6·88	11·20
Magnesia	4·24	4·46	3·81	2·29
Potash	1·08	1·58	1·92	1·38
Soda	2·98	2·59	2·56	2·04
Sulphur	·19	...	..	...
Carbonic acid	·30	..	trace	3·60
Phosphoric acid	.15	...	...	...
Titanic acid	trace	...	...	...
Water	1·25	1·50	...	1·55
	99·14	98·56	99·99	100·16

I. Specimen from Great Ayton. Analysis by W. F. K. Stock, Esq., of Darlington*.

II. Specimen from Armathwaite, about 60 miles from Ayton in a direct line. Analysis by W. F. K. Stock, Esq.

III. Specimen from Great Ayton. Analysis by J. E. Stead, Esq.

IV. Altered specimen from the margin of the dyke at Preston. Analysis by J. E. Stead, Esq.

Note on the Action of Hydrochloric Acid on the Rock of the Cockfield and Armathwaite Dyke. By W. F. K. Stock, Esq., Darlington.

The following investigation was suggested by the apparent ease with which a notable quantity of the Cockfield Armathwaite rock was acted upon by hydrochloric acid in open flasks, and by the fact communicated to me by Mr. James I'Anson, of Darlington, that sections cut by him showed a large proportion of matter wanting in definite form. The Ayton rock was first examined. A portion was reduced to an extremely finely divided condition by long-continued trituration in an agate mortar. About 2 grammes of the fine powder were sealed up in a pressure-tube of strong Bohemian glass along with 20 c.c. of hydrochloric acid of sp. gr. 1·16. The tube with its contents was exposed in an air-bath to a

* This analysis of the Ayton rock was originally prepared for Mr. I'Anson; but, thanks to the kindness of the latter gentleman, I am able to give it in this paper.

temperature ranging between 220° and 240° Fahr. for 24 days; at the end of that time the tube was opened under water and the contents filtered off. The insoluble portion was washed off the filter and treated with a ten-per-cent. solution of caustic potash to remove deposited silica. The washed residue was dried and heated to near redness and weighed. It was again ground down for a long time in the agate mortar, and an aliquot part sealed up once more with hydrochloric acid and exposed for fourteen days as before. It was found that in the second treatment only about 16 per cent. by weight had been dissolved, which seemed to afford good evidence that what remained was quite insoluble in hydrochloric acid under these conditions. The quantitative results obtained were that 39·33 per cent. of the Ayton rock was *insoluble in hydrochloric acid*, and that on determining the silica in this residue it was found to amount to 77·66 per cent. These results were verified by repetition.

After the analysis of the Armathwaite specimen had been completed, it was thought desirable to subject a portion of this rock also to the foregoing treatment. This was done; but the time of exposure was extended to 31 days, and the temperature was raised to 316°·4 Fahr. Under these conditions several tubes were lost by explosion. The insoluble residue amounted to 35·57 per cent. It was analyzed and furnished the following :—

Silica	25·17	70·76
Alumina	3·89	10·93
Ferric oxide	1·28	3·59
Lime.....	1·17	3·29
Magnesia	1·50	4·21
Alkalies	2·56	7·22
	35·57	100·00

Mr. I'Anson examined portions of the insoluble residue from time to time, duplicate tubes being prepared for that purpose, and in the final residues he found the doubly refracting matter to be reduced to a minimum.

Deducing an opinion from the almost total insolubility of these residues, their highly acidic character, and the absence of any marked amount of doubly refractive matter, I think we may regard them, at any rate approximately, as representing the base of the rock. This view is much strengthened by the results from the Armathwaite specimen which Mr. Teall handed to me as a rock with " a true glassy base;" nothing could much better represent a glass than the composition of this residue.

It may be of interest to state that in these tube-experiments it was conclusively proved that the hydrochloric acid took up none of the silica from the decomposable silicates, but that the whole of it was deposited in a pulverulent form in the tube, and was filtered off with the insoluble residue, from which it was, of course, separated by the treatment with caustic potash. This is a point which I have not seen noticed previously.

General Relations of the Rock forming the Cockfield and Armathwaite Dyke.

The rock has generally been considered a basalt; but it differs from typical basalts in many ways: thus olivine is entirely absent, and the bisilicate constituent plays a very subordinate part in the mineralogical composition of the rock. Then, again, the silica percentage (57 to 59) is much too high, that of true basalts averaging about 50 or less, and the specific gravity (2·77) is too low. The presence in considerable quantity of a highly acid base is also another point which distinguishes this rock from true basalts. Now in all these points the rock approaches the andesites and trachytes; and if the term augite-andesite is to be used at all, it seems fairly applicable to this rock, which, be it remembered, is almost certainly of Tertiary age.

I append a Table of analyses of recognized augite-andesites to show that there is a close correspondence between them and the rock now under special consideration:—

	I.	II.	III.	IV.	V.
Silica	57·80	59·70	58·76	57·51	56·582
Alumina	18·07	16·16	17·34	16·83	18·379
Ferric oxide	8·98	7·97	7·77	10·40	1·112
Ferrous oxide	.....	0·83	.....	.....	5·995
Manganese oxide	.....	.....	.....	.....	0·108
Lime	4·69	8·01	7·46	6·54	11·053
Magnesia	1·12	1·16	2·67	1·89	3·239
Potash	2·61	1·56	0·93	2·21	0·912
Soda	4·60	3·12	2·36	3·86	2·589
Loss	1·18	1·09	2·10	0·43	.....
	99·05	99·60	99·39	99·67	99·969

I. Augite-andesite Lava, Polsiegy near Szkaros.—Dr. C. Dölter, "Ueber einige Trachyte des Tokaj-Eperieser Gebirges," Min. Mitth. 1874, Heft iii. p. 213.

II. Augite-andesite from Köhegy near Bogdanz Garbocz.—Dr. C. Dölter, Min. Mitth. 1874, Heft iii. p. 207.

III. Porphyritic Augite-andesite from Tuhrina.—Dr. C. Dölter, Min. Mitth. 1874, Heft iii. p. 205.

IV. Lava of Pariou, ending at Fontmort, Clermont Ferrand.—Von Lasaulx, "Petrographische Studien an den vulkanischen Gesteinen der Auvergne," Neues Jahrbuch, 1871, p. 682.

V. Lava of Masaya Mindiri, Central America.—H. R. Marx, "Beitrag zur Kenntniss centralamerikanischer Laven," Zeitschr. d. geol. Ges. xx. p. 526 (1868).

The bulk analysis of our rock also bears a close resemblance to that of many of the so-called melaphyres, as will be seen at once by referring to the collection of analyses published in Zirkel's 'Lehrbuch der Petrographie,' vol. ii. p. 55. It should be borne in mind that the rocks to which the term melaphyre has been applied on the continent have, as a rule, a higher silica percentage, a lower specific gravity, and a larger proportion of felspar than the basalts.

The affinities of melaphyre are therefore rather with the augite-andesites than with the true basalts.

Many of the so-called augite-andesites contain a rhombic pyroxene; and it has been suggested by Mr. Whitman Cross ('Amer. Journ. of Science,' Feb. 1883), in a paper on the andesite of Buffalo Peaks, Colorado, that this rhombic pyroxene (hypersthene) is the predominating bisilicate in these rocks *. If this should turn out to be correct then they would have to be termed hypersthene-andesites, and the question would arise as to whether the term augite-andesite should be retained at all. I think in any case, however, the term augite-andesite is useful to indicate such a rock as the one described above, that is a plagioclase-augite-magnetite rock, having more or less a trachytic or andesitic structure, a silica percentage considerably higher than that of normal basalts, and a specific gravity of about 2·7. At the same time it must be admitted that such a rock is not separated from basalt by any hard-and-fast line; and from this point of view it might be called an andesitic basalt, except that this term has been used in a somewhat different sense by Bořický ('Basaltgesteine Böhmens,' p. 543).

A rock having essentially the same chemical and mineralogical composition has been described by Prof. A. Geikie, in a paper on the so-called Pitchstone of Eskdale ('Proceedings of the Royal Physical Society of Edinburgh,' vol. v. 1880). The Pitchstone of Jameson is shown to be merely a glassy form of this rock. My attention was called to this paper by Mr. Topley, after the above description of the microscopic character of the Cockfield and Armathwaite rock had been written. I mention this because there is a very striking resemblance between the way in which Prof. Geikie has described the devitrification-products of the so-called pitchstone and the manner in which I have described the precisely similar bodies in the Armathwaite specimen. The figure which Prof. Geikie gives in the paper above quoted, and also in his 'Text-book of Geology,' p. 100, exactly represents the special features of the base of the Armathwaite specimen (compare Pl. XII. fig. 2 *a*).

It may be as well to quote the bulk-analysis of the Eskdale rock:—

Silica	58·67
Alumina	14·37
Ferrous oxide	6·94
Ferric oxide	1·64
Manganese oxide	trace
Lime	7·39
Magnesia	4·65
Potash	1·42
Soda	3·01
Water	2·02
	100·11

* See also Bulletin of the U.S. Survey, no. 1.

The Hett Dyke.

Literature.

Sedgwick, Rev. Adam. "Geological Structure and internal Relations of the Magnesian Limestone," Trans. Geol. Soc. 2nd ser. vol. iii. part i.

——. "On the Phenomena connected with some Trap-dykes in Yorkshire and Durham," Trans. Cambr. Phil. Soc. vol. ii.

Bell, I. Lowthian. "On some supposed Changes Basaltic Veins have suffered during their passage through and contact with Stratified Rocks, and on the manner in which these rocks have been affected by the heated Basalt," Proceedings of the Royal Society, 1875, p. 543.

This dyke crosses the following 1-inch Ordnance Maps: 103° N.E., N.W., and S.W. Its course is thus traced by Professor Sedgwick * on the authority of Mr. Wharton, of Oswald House, Durham:—"It ranges from the escarpment of Magnesian Limestone (at Quarrington Hill, a few miles to the east of Durham), through the great coal-field, in a direction about W.S.W. It is found along this line at Crowtrees, Tarsdale, Hett, Tudhoe, Whitworth, and Constantine Farm. From the last-mentioned place it passes along the same line of bearing through the collieries of Bitchburn and Hargill Hill to a spot near the confluence of the Bedburn Beck and the river Wear, where it is well exposed at the surface of the ground; and it is known to pass up the Bedburn-Beck valley to Egglestone Moor." The author also states that the dyke increases in width in its progress westward from 6½ feet at Crowtrees to 15 feet at Bitchburn Beck.

The dyke has formerly been quarried on an extensive scale between the villages of Tudhoe and Hett. At present (1882) it is worked by means of shafts at Tudhoe, near the Darlington road, and at Hett village. Between the Darlington-road shaft and Hett village its course is marked by a nearly continuous trench, the result of old quarrying operations, which terminates at the village in a vertical face of rock. The direction of this trench is nearly east and west. At Hett the dyke is 10 feet wide, and hades to the north at a very high angle. The adjacent rocks are coal-shales which have been baked and indurated by the action of the igneous mass. A rude spheroidal structure has been brought to light by the action of the weather. This dyke, like the one already described, appears to keep its character for great distances; and although I have only examined it between Tudhoe and Hett, I have no doubt that the following petrological description will apply to it throughout its entire length.

Macroscopically it is a fine- or medium-grained crystalline rock of a dark grey or bluish-grey colour and a subconchoidal fracture. It can be at once distinguished from the rock of the Cleveland dyke by the absence of any porphyritic crystals of felspar. Here and

* Trans. Cambr. Phil. Soc. vol. ii. (1827).

there small spherical amygdaloids, for the most part filled with calcite, may be recognized. The texture of the rock does not vary in any marked manner, the individual constituents being, as a rule, just recognizable by the naked eye. On applying acid, a slight effervescence may frequently be observed, and this naturally becomes more marked near the edges of the dyke and in the neighbourhood of joint-planes.

Under the microscope the rock is seen to consist for the most part of felspar, pyroxene, and magnetite. There is, however, also a small quantity of cryptocrystalline matter (Pl. XII. fig. 5).

Felspar.—This occurs in forms which give lath-shaped sections, whose dimensions lie, as a rule, between the following limits:— ·08 × ·3 millim. and ·02 × ·14 millim. The length of a section is, on the average, about five times its width. I am not able to recognize more than one generation of felspar, so that the rock would be granular in the sense in which that term is used by Prof. Rosenbusch *. Under crossed Nicols the sections are seen to consist of two or more lamellæ; but simple individuals are by no means uncommon. When the thin sections are exposed for some hours to the action of hydrochloric acid at a temperature of 100° C. the felspars lose their individual action on polarized light; and I conclude from this, as well as from the bulk-analysis of the rock, that they belong to a species allied to labradorite.

Pyroxene.—This mineral rarely, if ever, presents definite crystalline boundaries. It occurs in isolated grains, granular aggregates, and irregular plates, which are frequently interpenetrated by the lath-shaped felspars. There is no doubt, therefore, that it consolidated after the felspar. The prismatic cleavages are the only ones that I have observed. Twinning is not uncommon.

Magnetite occurs in grains and crystals scattered uniformly through the rock, the sections measuring about ·12 or ·1 millim. across. That it is magnetite and not ilmenite appears to be proved by its tendency to give rise to limonite decomposition-products, and by the readiness with which it is attacked or removed by hot hydrochloric acid.

The elements already described make up perhaps nine tenths of the mass. As already stated, however, there occurs also a small quantity of interstitial matter which gives an indistinct reaction under crossed Nicols; it is brown in colour, granular in aspect, and usually charged with minute colourless acicular microlites. This doubtless represents the highly acid residue which remained after the separation of the definitely crystalline constituents. The secondary minerals are calcite and quartz. Green alteration-products are very rare in the specimens examined by myself.

The specific gravity of the unaltered rock varies from 2·94 to 2·96. Its chemical composition, as given by Mr. I. Lowthian Bell, F.R.S., is as follows:—

* "Ueber das Wesen der körnigen und porphyrischen Structur bei Massengesteinen," Neues Jahrbuch (1882), Band ii. p. 1.

Silica	51·35
Alumina	17·61
Ferrous oxide	12·04
Lime	9·65
Magnesia	5·68
Potash	1·40
Soda	0·56
Carbonic acid	1·53
	99·82

About 2 miles to the north of the Hett dyke is another dyke of almost identical composition (see Mr. Bell's paper, p. 546); and between the two there occurs, at a depth of about 60 fathoms beneath the surface, a horizontal sheet of similar material, which was proved, by the mining operations of Messrs. Bell Brothers, to cover an area of at least 15 acres, and to be in one place 19·75 feet in thickness. Mr. Ernest Bell forwarded a piece of this rock to Dr. Trechmann; and to the latter gentleman I am indebted for the specimen on which the following statements are based. The rock is identical in appearance with the more coarsely crystalline varieties of the Hett dyke. Microscopically, also, there is the closest resemblance, the principal difference being the almost entire absence, in the case of the intrusive sheet, of any interstitial matter. The specific gravity of my specimen is 2·96, and the chemical composition of the sheet, as given in Mr. Bell's paper, is:—

Silica	51·90
Alumina	15·46
Ferrous oxide	12·87
Lime	13·80
Magnesia	4·02
Potash	1·21
Soda	0·48
Carbonic acid	1·02
	100·76

Of what age are these dykes? To this question no definite answer can be given. There is no evidence that either of them penetrates the Magnesian Limestone, although they are known to occur in the Coal-measures beneath. Prof. Sedgwick remarks that the Hett dyke can be traced to Quarrington Hill, but that it does not pass up into the Permian; and from this fact he is inclined to regard it as of Palæozoic age. It is worthy of note that the rock of which these dykes and the accompanying "sill" are composed differs in a marked manner from that of the Cleveland dyke; it is more basic in composition, of higher specific gravity, and much more largely composed of crystalline constituents. In all these points it approaches in character the rock of the Great Whinsill, with which I am strongly inclined to regard it as contemporaneous.

The Hebburn Dyke.

Literature.

Winch, N. J. "Observations on the Geology of Northumberland and Durham," Trans. Geol. Soc. vol. iv. (1827).

Lebour, Prof. G. A. Outlines of the Geology of Northumberland (1878), p. 48.

Ordnance Maps (1 inch). 105 S.E. and S.W.

This dyke is described by Prof. Lebour as emerging from beneath the Magnesian Limestone near Cleadon, and passing in a W.N.W. direction by Hedworth and Hebburn to the Tyne at Walker, where it enters Northumberland. There is, so far as I know, no exposure of this dyke at the surface now known; but Winch describes a quarry which was formerly worked about 1 mile north of the Boldon Hills. "The rock," he says, "was fine-grained, nearly black, and filled with small globules of milk-white chalcedony not bigger than a mustard-seed."

The course of this dyke, as marked on the Survey maps, has therefore been traced by means of the data supplied by the numerous colliery workings in the district. Prof. Lebour regards the celebrated Coley-Hill dyke, which was formerly worked on such an extensive scale to the west of Newcastle, as a continuation of the Hebburn dyke; but as the former agrees very well in direction with the Tynemouth dyke, with which it has also very close petrological affinities, I am inclined to regard it rather as a continuation of the latter than of the former. When speaking of the relations of the dykes of Coley Hill, Walker, and Boldon, Mr. Winch says:—"It is by no means ascertained that they are portions of the same dyke connected together below the surface, since no trace of that of Coley Hill could be discovered in the very extensive and ancient collieries of Montagu and Kenton, situated in its course at a short distance to the east of it: nor was the Walker dyke found in any other quarry."

The only locality where I have had an opportunity of examining

Fig. 2.—*Dyke in Coal-measures, Boldon Pit.*

A. Bad coal, slightly charred, 8 yards. B. Greyish black cinder, 12 yards.
C. Greyish black cinder.

the Hebburn dyke is in Boldon pit. To this exposure I was conducted through the kindness of Mr. Walker, who also supplied me with a sketch from which the diagram (fig. 2), expressing the relation of the whinstone to the Coal-measures, is constructed. The section crosses the dyke about 22° from a right angle.

The actual thickness of the dyke in the "blue metal" is thus seen to be 44′ 6″, and in the coal 49′.

Macroscopically the rock is dark, almost black in colour and uniformly crystalline in texture, *i. e.* porphyritic elements are wanting. At the margins it is compact. In the central parts it effervesces slightly, and in the marginal parts freely with hydrochloric acid. Here and there occur small spherical amygdaloids, measuring on the average about 1 mm. in diameter; these are occupied by calcite and quartz. The specific gravity of the unaltered rock is 2·84.

Under the microscope the rock is seen to consist of magnetite (? ilmenite), felspar, pyroxene, and a considerable quantity of interstitial matter, which has a decided though indefinite reaction on polarized light. This ground-paste is rendered in places almost opaque by a large quantity of brown granular matter. It also contains skeleton felspars and acicular microlites of felspar, which do not always appear to be sharply separated from the paste.

The felspar sections are usually very long in proportion to their width, a feature which characterizes many of the dykes now about to be described (Pl. XII. fig. 6). Binary twins are most numerous. The pyroxene is almost colourless, frequently twinned and evidently monoclinic; it occurs in irregular plates of secondary consolidation and rarely, if ever, shows definite crystalline boundaries in those sections which are taken from the main mass of the dyke.

The mutual relation of the felspar and pyroxene is that so eminently characteristic of the German and Swedish diabases, but which is also found in certain typical dolerites.

The secondary products are calcite, quartz, and a greenish serpentinous mineral giving aggregate polarization. The latter mineral occurs sparingly, and may possibly be a pseudomorph after olivine. Calcite and quartz occur in the spherical amygdaloids already mentioned, the former mineral making up the central and larger portion of the amygdule, and the latter occurring as detached crystals or crystalline granular aggregates near the periphery. It is especially worthy of note that the lath-shaped felspar sections are frequently arranged with their longer axes parallel to the boundaries of the amygdaloids, a fact which can only be explained by supposing that the cavities were produced when the rock was plastic. The presence of gas-cavities in a rock which was evidently produced under great pressure is somewhat anomalous.

The marginal portion differs in texture from the main mass of the dyke. It is micro-porphyritic; but, owing to the enormous amount of alteration which has taken place, it is somewhat difficult to make out its original character. The larger constituents are irregular grains of magnetite, lath-shaped felspars, frequently having bifid

and ragged terminations, and green pseudomorphs after a pyroxene having definite crystalline boundaries; both the six- and eight-sided forms characteristic of sections of augite parallel to the orthopinakoid, and at right angles to the vertical axis, may be easily recognized. The ground-mass is a confused aggregate of extremely minute felspar microlites, specks of opacite, and indistinct brownish granules. Isotropic glass may or may not be present; a considerable amount of calcite in the form of crystalline powder is scattered throughout the mass.

The absence of well-formed augites in the main mass of the dyke, and their presence in the more rapidly cooled marginal portions, is a fact of some considerable importance, as apparently showing that the period of consolidation of the augite is dependent rather upon physical than upon chemical conditions. In microscopic structure the rock of the Hebburn dyke differs from that of either of the dykes already referred to and approximates very closely to that of several dykes now to be described.

Is this dyke of Tertiary or pre-Tertiary age? No definite answer can be given to this question. It is not known to cut any formation of later date than the Coal-measures.

The Tynemouth Dyke.

Literature.

Winch, N. J. "Geology of Northumberland and Durham," Trans. Geol. Soc. vol. iv.

Lebour, Prof. G. A. Outline of the Geology of Northumberland (1878).

Ordnance Maps 105 N.E. and N.W.

This dyke is exposed at the base of the Castle Rock, Tynemouth. It may be examined on the shore in the angle formed by the meeting of the breakwater and the coast-line, where it is seen in contact with Coal-measure strata on the north, and with the wall of the breakwater on the south. Permian strata cap the hill on which the Priory stands; but the dyke is not seen in contact with these beds. It is about 10 feet wide, and separated into two portions by a quartzose vein which is 6 inches wide. The same dyke was also admirably exposed during the construction of the new railway station at Tynemouth in the winter of 1881 and 1882.

The most interesting feature connected with this exposure was the evidence of a breach in the continuity of the dyke, accompanied by a lateral shift in the outcrop, amounting to 17 yards. The width of the dyke was about 11 or 12 feet, and it possessed a hade to the north. Further west the same dyke has been met with near Biddy Mill * by Mr. Flavell, F.G.S., during the construction of works by the North Shields Water Company. Still further to the west, near

* Lebour, 'Geology of Northumberland,' p. 48.

Newcastle, occurs the well-known Coley-hill dyke, which was formerly worked on a very extensive scale for road-metal, and the course of which is now indicated by a deep trench. This dyke agrees very well in direction with the Tynemouth dyke, and Winch appears to have regarded the two as connected.

I was not able to find the Coley-hill rock *in situ*; but some large angular fragments were found in the trench at one point, and as these agree with the description gived by Winch, I have no doubt that they were portions of the dyke. If so, they prove that the petrological characters of the Coley-hill dyke agree with those of the Tynemouth dyke, and differ from those of the Hebburn dyke, a fact which seems to establish the connexion of the two former.

I now proceed to describe the rock of the Tynemouth dyke. It varies in aspect according to the presence or absence of (*a*) porphyritic crystals of anorthite and (*b*) small spherical amygdaloids. The porphyritic crystals frequently measure more than 1 centim. in cross section; they are, as a rule, very irregular, and consist rather of crystalline aggregates than of simple crystals; nevertheless sections parallel to the basal plane, showing the forms $\infty \breve{P}\infty$, ∞ P′, and ∞ ′P, are not uncommon. These sections show also the striation characteristic of plagioclase. The crystals are glassy in texture, but they frequently show a slight tinge of yellow. Isolated fragments of these felspars were analyzed by my friend Mr. Stead, with the following result:—

Silica	47·30
Alumina	31·50
Ferric oxide	1·85
Lime	14·88
Magnesia	0·93
Potash	38
Soda	1·22
Loss	1·80
	99·86

It is impossible to obtain the felspar in a state of absolute purity, on account of the numerous inclusions which it contains; and it will also be shown further on that the outer zone of felspar substance possesses optical properties somewhat different from the central portion; nevertheless the analysis clearly proves that the felspar is closely allied to anorthite. A section of the felspar specially prepared and approximately parallel to the basal plane gave 55° 10′ as the angle between the extinction-positions of adjacent lamellæ. The corresponding angle in anorthite, according to Lévy and Fouqué, lies between 57° and 74°, and in labradorite between 10° and 14° 30′. Assuming Schuster's interpretation of Tschermak's theory to be correct, then this figure corresponds to about 90 per cent. of anorthite in the mixture. The above facts with regard to the Tynemouth felspars have appeared in the Geol.

Mag. decade ii. vol. x. p. 252 ; but they are again inserted here in order to make the description of the Tynemouth rock complete.

The spherical amygdaloids, like the porphyritic crystals, are very abundant in certain specimens and almost entirely absent in others; they vary in size from that of a mustard-seed to that of a peppercorn, and, as a general rule, where the amygdaloids are most numerous the porphyritic crystals are least numerous, and *vice versâ*. The amygdules effervesce freely with hydrochloric acid and are thus seen to be largely composed of calcite.

The ground-mass of the rock in which the above elements occur is crystalline in texture and of a very dark colour. Fractured surfaces are somewhat uneven. A bulk-analysis of the rock yielded to Mr. Stead the following result:—

Silica	58·30
Alumina	16·14
Ferrous oxide	4·50
Ferric oxide	4·76
Lime	10·96
Magnesia	2·68
Potash	0·94
Soda	1·74
	100·02

Three separate determinations of the density gave 2·844, 2·845, 2·839.

Under the microscope (Pl. XIII. fig. 1) the ground-mass is seen to be identical with that of the Hebburn dyke; it is therefore unnecessary to describe it in detail. In two out of the seven slides examined the serpentinous mineral appears to form a pseudomorph after olivine; and we may conclude, I think, that olivine was sparingly present in the original rock. The large porphyritic crystals call for more detailed description. Under polarized light they are at once seen to consist, as a rule, of crystalline granular aggregates, as many as 7 or 8 crystalline grains going to make up one of the larger porphyritic masses. The different individuals in a complex mass are not orientated in any definite manner with regard to each other, *nor do the interior boundaries of the crystalline particles show definite faces, although the external boundaries usually do*. Another feature of great interest is to be found in the fact that a narrow peripheral zone of felspar substance is usually present, which extinguishes at a different angle from the central kernel, and that it is this peripheral zone which gives the definite crystalline form to many of the grains. I have never seen this zone continued between two individual grains of one and the same aggregate.

It appears, then, that granular aggregates of anorthite were first formed without external crystalline faces, and that, during the later stages of consolidation, additional felspar substance of somewhat different composition was added, so as to give definite form to the

external portions of individual grains—that is, to those portions which were in contact with the consolidating magma (Pl. XIII. fig. 1).

The porphyritic felspars frequently contain large numbers of minute (·004 mm.) elliptical inclusions of a brownish glass, and sometimes large, irregular, and nearly opaque masses of the ground-paste. Augite granules are not uncommon in the peripheral zone. Under crossed Nicols two types of twinning may be recognized, the lamellæ of the prevailing type being usually broad and frequently terminating in the centre of a crystal or crystalline grain.

The microscopic structure of the amygdaloids has been already described in connexion with the Hebburn dyke.

An experiment was made to ascertain the relative fusibility of the ground-mass of this rock and the porphyritic crystals. Several pounds weight were placed in a crucible, and subjected to the heat of a brass furnace. It was found that this was sufficient to melt the ground-mass; but the large felspars remained intact, so that after rapid cooling they were found imbedded in a brown isotropic glass. In a second experiment the cooling was prolonged for fourteen hours, and it was then ascertained that dense spherulites similar to those of the tachylite (? hyalomelan) of Sababurg had developed themselves, and that a similar mode of devitrification had taken place round each of the porphyritic crystals.

Brunton Dyke.

Literature.

Lebour, Prof. G. A. Geology of Northumberland. Ordnance Map 106 N.E.

The course of this dyke in thus described by Prof. Lebour:—"The Brunton dyke, known in west Allendale, near Whitfield, crosses the South Tyne first to the west of Haydon Bridge, then between that little town and Wharnley, and lastly to the east of the latter place; it crosses the North Tyne near Wall, is well exposed by St. Oswald's Chapel, near Brunton, and is last seen in the Bingfield Burn on the east side of the Watling Street. Two small dykes run close to and parallel with this one near its easternmost extremity. Of these one is well seen in the Bingfield Burn, and the other in the bed of the Pont, where that little stream crosses the Watling Street."

The general trend of the main dyke appears to be nearly N.E. and S.W. On Feb. 2, 1882, I had the opportunity of examining two of the dykes above referred to in company with Mr. I'Anson. We were directed to the spot by Prof. Lebour. They are exposed in the small burn which crosses the Watling Street about half a mile W.S.W. of Bingfield. Leaving the road at this point and working up the stream for a quarter of a mile, or rather less, we see the main dyke exposed on the south side of the stream, where it is intrusive in encrinital limestone. The main mass is composed of a

dark grey, or greenish-grey, finely crystalline rock, portions of which bear a very close resemblance to the ground-mass of the Tynemouth dyke. Porphyritic crystals of felspar are very rare, but not entirely absent. At the north-west margin there occurs a considerable thickness, perhaps 12 or 14 feet, of what appears to be highly altered whinstone. This varies in colour from a light grey to a dark greenish grey, with narrow zones of brown due to the segregation of iron oxides along bounding surfaces and joint-planes. The altered portion usually effervesces very freely with hydrochloric acid; and cracks and amygdaloidal cavities filled with calcite and chalcedony are very abundant. The total thickness of the dyke is about 20 or 25 feet.

Under the microscope the central and comparatively unaltered portions are seen to consist of long narrow lath-shaped felspars, irregular crystalline grains and plates of a nearly colourless pyroxene, and a small quantity of nearly opaque interstitial matter. The iron oxide does not seem to have separated out, but to have remained in solution in the paste until the final act of consolidation took place. This is probably only a local peculiarity (Pl. XII. fig. 6). The marginal portions of the dyke are so much altered that it is difficult to make out their original characters under the microscope. It is worthy of note, however, that the felspars are comparatively fresh even when the other constituents have lost all their original characters. The amygdaloids and veins of calcite and chalcedony do not call for any special description. The specific gravity of the rock is 2·9.

The Seaton and Hartley Dykes.

Literature.

Lebour, Prof. G. A. Geology of Northumberland, p. 48.
Ordnance Maps 105 N.E. and N.W.

In this district there are several parallel dykes running at short distances from each other in a direction slightly N. of W. and S. of E. They are exposed on the shore between Seaton and Hartley (one near the northern angle of the shore and another near the spring which rises on the shore), in the small valley to the west of the village, where they are now (1882) being quarried for road-metal, and also in the Shankhouse collieries further west. At page 48 of his 'Geology of Northumberland,' Prof. Lebour writes:—"In some cases the actual natural top or vertical dying-out of a dyke may be seen, as on the coast a little to the south of Seaton Sluice. Here, near a spring on the beach, a dyke, at least 12 feet in width where it rises at the foot of the cliff, is finely shown ending off in two tongues of basalt, the longest of which, after curving amongst disturbed and contorted shale, dies out about 11 feet from the ground beneath a bed of sandstone, which it had not the force to break through. The fault along which this dyke was injected is well seen continuing its upward course." At the time of my visit this section was obscure,

but the same feature was exposed in a small quarry on the east side of the dene, a few hundred yards inland. The dyke here was about 10 feet wide at the bottom and 5 feet at the top of the quarry, the depth exposed being about 20 feet; it terminated upwards in an abrupt manner, and the indurated shales which were continuous over the top showed a slight upward arching. Macroscopically and microscopically the rock bears the closest resemblance to that last described.

Through the kindness of Messrs. Linsby and Ormsby, I was conducted to two exposures in the Shankhouse pit. The south dyke was here seen to be 7 or 8 feet wide, its centre being occupied by a rubbly mass containing angular fragments of whin and Coal-measure strata; Mr. Paterson, the overman, informed me that this was a common feature in the dykes of this district. I presume that the centre has in many cases been a plane of weakness, owing to cooling from opposite sides, and that subsequent movement has taken place along this plane, giving rise to a fault-breccia. The northern exposure in this colliery showed two parallel dykes, one measuring several feet and the other only 11 inches in thickness. These two dykes run together into one within the limits of the same royalty. The coal was much charred in the neighbourhood of the igneous rock, which was seen in one case to send off narrow irregular veins. The narrow dykes and veins were altered to the condition of "white trap" *.

Numerous specimens from these dykes as they are exposed on the shore near Seaton, in the dene, and in the Shankhouse pit have been examined both macroscopically and microscopically. Everywhere they present the same features. The rock is dark, in some cases almost black in colour and finely crystalline in texture. Porphyritic elements are very rare, but now and then crystals of felspar, similar to those of the Tynemouth rock and doubtless belonging to the same species, may be recognized. In some specimens the small spherical amygdaloids are not uncommon. Alteration at the surface gives rise to the characteristic brown colours; but in the pit these are never observed, the large amount of organic matter causing the water to act as a reducing, instead of an oxidizing agent. The specific gravity of the rock varies from 2·81 to 2·824.

Under the microscope one recognizes long narrow sections of plagioclase, irregular grains and plates of a colourless pyroxene, and a certain amount of interstitial matter rendered more or less opaque by various devitrification-products, and especially by small crystals, rods, and granules of magnetite. In some cases the ultimate base is seen to be a rich brown isotropic glass. The secondary products comprise, as usual, calcite, quartz, pyrites, and a yellowish-green substance giving aggregate polarization. The latter product, however, is by no means invariably present. A section of the white altered rock from the pit shows the felspar fresh, and the pyroxene replaced by calcite.

* Jukes, 'South Staffordshire Coal Field,' 2nd edit. p. 118.

Morpeth Dyke.

Literature.

Lebour, Prof. G. A. Geology of Northumberland, p. 48.
Ordnance Map 105 N.W.

Specimens of this dyke have been kindly given to me by Prof. Lebour. It crosses the Wansbeck a few yards below the viaduct of the North-Eastern Railway near Morpeth ('Geology of Northumberland,' p. 48). The rock is somewhat blacker and more closely crystalline than that of the dykes hitherto described; it is also denser, its specific gravity lying between 2·88 and 2·89. Crystals and crystalline granular aggregates of felspar (? anorthite) occur as porphyritic elements; but as they do not differ markedly in size from the larger felspars of the ground-mass, they are not so easily recognized in the hand-specimen as in the thin section.

Mr. Stead has analyzed the rock with the following result:—

Silica	51·20
Alumina	20·03
Ferric oxide	7·57
Lime	10·52
Magnesia	6·75
Potash	0·51
Soda	1·71
Water	1·70
	99·99

Under the microscope the rock is seen to have very close relations with that of the Tynemouth and the related dykes. There are the same porphyritic felspars and amygdaloids, although these are not nearly so abundant or so large as in the Tynemouth rock, and the same long lath-shaped felspar sections, irregular grains and plates of pyroxene, and interstitial matter, with its various devitrification-products. There is, however, one important point of difference: olivine, both fresh and in the form of a green and brown serpentinous pseudomorph, is comparatively abundant in this rock. This occurrence is of some interest, on account of the rarity of this mineral in the rocks described in this paper; indeed this is the only rock here referred to in which I have detected the mineral in an unaltered condition.

It must not be supposed, however, that this fact differentiates the Morpeth dyke from the dykes of Hebburn, Tynemouth, Brunton, Seaton, and Hartley; for in all other points there is the closest resemblance between them; and, moreover, pseudomorphs after olivine occur sparingly in the Tynemouth and probably also in the other dykes.

High-Green Dykes.

Literature.

Lebour, Prof. G. A. Geology of Northumberland, p. 50.
Ordnance Map 108 S.E.

Two dykes, presenting a type of structure in some respects different from that of any of those previously described, are exposed on the east side of the Tarret, near High Green, a farmhouse about 5 miles N.N.W. of Bellingham. My attention was first called to these dykes by Prof. Lebour, and subsequently Mr. Howell was kind enough to mark them in for me on my maps.

The first to be described strikes W. 10° S., E. 10° N., and crosses the Tarret Burn at a point W.S.W. of High Green. It is well exposed in the bed and along the sides of the stream, where it is about 50 feet thick. The central portions are coarsely and uniformly crystalline in texture; but the margins, where not highly altered, are finely crystalline or even compact. The only elements which can be distinctly made out with a hand-lens are felspar and pyrites, the latter mineral occurring very sparingly and only in certain specimens.

Its specific gravity lies between 2·9 and 2·93, and its chemical composition, as determined by Mr. Stead, is as follows :—

Silica	53·70
Alumina	18·21
Ferric oxide	10·64
Lime	6·66
Magnesia	5·24
Potash	0·99
Soda	2·65
Water	1·55
	99·64

One of the most interesting features connected with this dyke is its mode of alteration at the north margin. The rock there shows a cellular structure, evidently connected with its mode of jointing. The walls of the cells are formed of a deep brown and comparatively hard substance, evidently rich in hydrated ferric oxide, while the cells themselves are filled with a friable white or cream-coloured material. On analysis these two substances yielded to Mr. Stead the following results :—

	Cell-walls.	Cell-contents.
Silica	43·50	66·20
Alumina	14·61	23·92
Ferric oxide	31·14	0·78
Lime	0·44	0·95
Magnesia	0·11	0·33
Carbonic acid	....	traces
Potash	0·09	0·04
Soda	0·26	0·57
Water	9·50	7·00
	99·65	99·79

On comparing these analyses with each other, and with the analysis of the comparatively unaltered rock, we see that the effect

of the alteration has been to remove the alkalies and alkaline earths, to introduce water, and to concentrate the iron in the form of hydrated peroxide along the margins of the joint-planes. It is not difficult to trace the probable steps by which these results have been brought about. In the first place the silicates would be decomposed by the action of water charged with carbonic acid; and the carbonates of lime, magnesia, and iron thus formed would be in part held in solution by an excess of carbonic acid. This solution would come into contact with oxygen along the joint-planes, and hydrated ferric oxide would be precipitated. Diffusion would tend to cause the carbonate of iron held in solution in the interior of the cells to move outwards, and thus fresh portions would be brought under the influence of the oxygen, obtaining access by means of the joint-planes, and a further precipitation of ferric oxide would take place. This process would be continued until the whole of the iron had been removed from the interior of the cell, and concentrated in the neighbourhood of the joint-planes. In short the action would be analogous to that described by Prof. Judd as having taken place in the case of the Northamptonshire iron-ore*. The carbonates of lime and magnesia would of course also be removed from the interior of the cells; but as there would be no chemical action tending to separate the lime and magnesia at the joint-planes, these bases would be completely removed by the percolating waters. Here, then, we witness the result of an interesting chemical operation: iron is separated from lime and magnesia by the action of oxygen on a solution of the carbonates; iron is precipitated as ferric oxide, while the carbonates of lime and magnesia remain in solution.

We return now to the description of the unaltered rock. Under the microscope (Pl. XIII. fig. 2) one recognizes felspar, pyroxene, and large plates of an opaque mineral, which appears to be ilmenite†, also colourless prisms of apatite. The rock is composed almost entirely of crystalline elements, and in structure is eminently diabasic (*structure ophitique* of Lévy and Fouqué and *diabasisch-körnig* of Rosenbusch).

Felspar.—This mineral occurs in lath-shaped sections, usually three or four times as long as broad. In the Tynemouth dyke and its associates the corresponding felspars, as we have seen, are very long in proportion to their width. Another point of difference lies in the fact that the felspars in the High-Green dyke are more or less altered, while those in the altered portions of the Tynemouth dyke are comparatively fresh. This probably indicates an important difference in chemical composition. Under polarized light, and in cases where the alteration has not proceeded so far as to destroy all individual action, the crystals are seen to consist of binary, or more frequently of multiple twins.

Pyroxene occurs as isolated crystalline grains and irregular plates;

* 'Geology of Rutland,' p. 133.

† Titanic acid was not estimated in the analysis, and is therefore weighed in part with the silica and in part with the alumina and iron.

but more frequently as crystalline granular aggregates. It appears, in the thin section, of a pale brown colour. Twinning is common, and the prismatic cleavages are usually well marked. The lath-shaped sections frequently interpenetrate the pyroxene, thus giving rise to the diabasic structure.

Ilmenite.—This occurs in large opaque plates of great irregularity, interpenetrated by the other crystalline elements. The habit of this mineral in the High-Green rock is exactly the same as in the diabases of the Hartz, Nassau, and Saxony, except that it is not altered into the white silico-titanate of lime.

The most important secondary product is a greenish serpentinous mineral containing specks and veins of opacite. This may possibly be a pseudomorph after olivine.

Rather more than a mile to the north of the dyke just described is another having a somewhat similar character. It is well exposed in an old quarry on the east side of the Tarret Burn, where it is 20 or 30 feet wide, and weathers in a markedly spheroidal manner. The rock is black in colour and distinctly crystalline in texture. Porphyritic elements are not distinctly recognizable by the naked eye; but under the microscope two generations of felspar are at once seen to be present.

The original constituents are felspar, pyroxene, ilmenite, apatite, and possibly also olivine. A very small quantity of a pale brown isotropic glass is present. If we except the earlier generation of felspars and the small quantity of isotropic glass, then there is the closest resemblance between this rock and that of the more southern dyke. The other constituents have the same individual characteristics and are similarly related to each other; they do not therefore call for any special description.

The felspars which give the porphyritic character to the rocks are few in number, and may be distinguished from the others by their form and by the presence of a large number of irregular ramifying inclusions of the ground-mass. The specific gravity of the rock is 2·92.

Acklington Dyke.

Literature.

Lebour, Prof. G. A. Geology of Northumberland, p. 49.
Ordnance Maps 109 S.W. and 108 N.E.

The course of this dyke is thus described by Prof. Lebour :—"It stretches across the entire width of the country from the coast at Boudicar, near Acklington, cutting through Coal-measures, Millstone Grit, the whole of the Bernicians, the Tuedians, and the Cheviot porphyrites. . . . . it runs on for many miles across the south of Scotland. It is well seen at numberless places along its course, notably at Debdon, Cartington Castle, and the road along the Coquet, near Shillmoor. At Acklington it is 30 feet wide."

I have examined it myself at the point where it crosses the Coquet, half a mile above the Mill, near Acklington Park, and again at two

points near Newton and Clennel, 17 or 18 miles further west. Also on the hills about 2 miles north-west of Alwinton, at the point where it crosses the Usway, half a mile above Shillmoor Farm, and, lastly, in the road along the Coquet, one mile above Shillmoor. At the two last-mentioned exposures the dyke is intrusive in Cheviot porphyrites.

Observations based on numerous specimens collected from the above localities prove that the rock of this dyke, like that of the Cleveland, Cockfield, and Armathwaite dyke, is remarkably constant, both in its macroscopic and microscopic characters, throughout the entire length examined. It is distinctly crystalline in texture, and of a bluish-grey colour when freshly broken. The colour, however, rapidly changes to black on exposure. Porphyritic crystals of felspar are not to be recognized by macroscopic examination; and in this respect there is a marked difference between the Acklington and Cleveland dykes. Determinations of the specific gravity of specimens from each of the above localities were made, with results varying from 2·805 to 2·817. The average may be taken as 2·81; and the deviations from this average, therefore, do not appear to reach more than two fifths per cent. Mr. Stead has analyzed the rock with the following result:—

Silica	57·80
Alumina	16·18
Ferric oxide*	10·07
Lime	6·18
Magnesia	4·68
Potash	0·77
Soda	2·38
Water	1·70
	99·76

Under the microscope the original constituents are seen to comprise felspar, pyroxene, magnetite, and interstitial matter, with various devitrification-products. The general structure reminds one of the ground-mass of the Cleveland, Cockfield, and Armathwaite dyke, except that the interstitial matter in this case is much less abundant.

Felspar.—The prevailing felspar occurs in lath-shaped sections similar in every respect to the small felspars of the Cleveland dyke. A detailed description is therefore unnecessary. In the majority of slides examined these are the only felspars to be recognized; but in one or two other forms occur which belong to an earlier generation, and therefore give the rocks a porphyritic character. These give sections more equal in the different directions; they contain numerous inclusions, and are usually composed of a central nucleus and a peripheral zone, which extinguish in slightly different positions.

Pyroxene occurs in crystalline grains and small imperfectly developed crystals, the latter sometimes elongated in the direction of the

* Total iron reckoned as Fe_2O_3.

vertical axis. Twinning is common, and cleavages are sometimes well shown. In thin sections this mineral is almost colourless.

Magnetite is present as small crystals, grains, and skeleton-crystals.

The interstitial matter is similar in every respect to that which is so common in the Cleveland dyke, and does not therefore call for special description. The secondary products are calcite and quartz. Pyrites also occurs. Amygdaloidal cavities containing a crystal of calcite surrounded by a narrow zone of chloritic material are found both at Debdon and Clennel.

The dyke is not known to intersect any formation of later date than the Coal-measures; but from the fact that it bears a close resemblance in character and direction to that of Cleveland, I am disposed to regard it as of Tertiary age.

Conclusion.

If we reconsider the facts recorded above, it will appear that the dykes to which reference has been made fall into four more or less distinct groups:—

1. (*a*) Cockfield, Cleveland, and Armathwaite dyke.
   (*b*) Acklington dyke.
2. The Hett and related dykes, including the "sill" in the Browny and Page-Bank collieries.
3. (*a*) The Hebburn dyke.
   (*b*) The Tynemouth dyke.
   (*c*) The Brunton dyke.
   (*d*) The Seaton and Hartley dykes.
   (*e*) The Morpeth dyke.
4. The High-Green dykes.

Groups 1 and 3 resemble each other in chemical composition and specific gravity; so also do groups 2 and 4. The former have a silica percentage varying from 57 to 59, if we except the somewhat abnormal Morpeth dyke (which appears in other respects to belong to group 3), and a specific gravity of about 2·7 or 2·8; the latter have a silica percentage varying from 51 to 53, and a somewhat higher specific gravity. Groups 1 and 3 are distinguished from each other by certain peculiarities of microscopic structure, which may or may not be related to a difference in geological age.

Groups 2 and 4 are closely related both in composition and structure, the principal difference being a pathological one. Alteration-products abound in group 4, but are for the most part absent from group 2.

If we consider the dykes with reference to the structures indicated by the terms "porphyritic," "granular," and "holocrystalline," as these are used by Prof. Rosenbusch, we find that the Hett and the High-Green dykes are almost, though not entirely, holo-

crystalline and granular; whereas the others contain a considerable amount of indistinctly individualized matter. All the dykes show occasional traces of two generations of felspar; but the only ones which are conspicuously porphyritic are those of Cleveland and Tynemouth.

The observations which have been made on the Cleveland, Acklington, and Hett dykes prove that the minute characters, both of composition and structure, are constant throughout great distances, and bear no relation to the surrounding rocks. These observations do not lend any support to the view that the igneous matter has taken up any appreciable portion of the sedimentary material into which it has penetrated. If we endeavour to give names to the rocks here described we are met by the difficulty arising from the absence of unanimity among petrologists as to the use of such terms as basalt, dolerite, augite-andesite, augite-porphyrite, diabase, and melaphyre.

In this country we find it quite impossible to apply any system of classification which primarily depends on a distinction between pre-Tertiary and post-Tertiary rocks, for the following reasons:— (1) The age of many of our eruptive rocks, including some of the dykes here referred to, cannot be determined by field-evidence; (2) rocks identical both in structure and composition, and belonging to the basic, intermediate, and acidic groups, have been formed at widely separated intervals of geological time.

If we assume, for the purpose of indicating the relations of our rocks with those of the continent, that groups 2, 3, and 4 are of pre-Tertiary age, then the Hett and High-Green dykes would have affinities with the diabases and augite-porphyrites, but would be more allied to the former than the latter. The High-Green dyke might almost be called a typical diabase; for the interstitial matter is hardly present in recognizable quantity, and the porphyritic felspars are very few and far between; they cannot be recognized without the microscope. In the mode of alteration of the rock and the character of the ilmenite it exactly resembles many of the continental diabases. The dyke to the north of High Green is more distinctly porphyritic, and indicates, therefore, a transition from the diabases to the melaphyres.

The dykes of group 3 would, on the continent, be described as melaphyres; indeed Prof. Rosenbusch speaks of a rock from Newcastle-on-Tyne, probably a portion of the Tynemouth and Coley-hill dyke, as a true melaphyre ('Massige Gesteine,' p. 410).

It is worthy of note that many of the rocks to which the term "melaphyre" has been applied have a higher silica percentage (about 56 per cent.) than dolerites and basalts. Thus they are described in the older petrology as consisting essentially of oligoclase and augite, whereas the felspar in the basalts is described as labradorite (Zirkel, Lehrb. d. Petrogr. 1866, Band ii. p. 39). If this view were generally accepted, then the melaphyres would bear the same relation to the augite-andesites as the diabases do to the dolerites.

The Cleveland, Cockfield, and Armathwaite dyke in composition, structure, and geological age is a pyroxene-andesite; and as the pyroxene is monoclinic, it may fairly be called an augite-andesite.

The classification of the rocks referred to in this paper would be greatly facilitated if we had a ready method of determining the felspars. Unfortunately we appear to have no such method. I have tried both alterability by acid and the method of extinction, as recommended by Messrs. Lévy and Fouqué. The results, however, have not been such as to give me confidence in their general applicability. When the crystals are sufficiently large to enable one to isolate fragments, then specific-gravity determinations and optical tests yield results which are doubtless thoroughly reliable. In conclusion I would remark that any system of classification, to be natural, should take into consideration all the characters of igneous rocks—chemical composition, mineralogical composition, microscopic structure, and mode of occurrence; and that in estimating the relative value of these characters great importance should be attached to the fact that the chemical composition of unaltered specimens is that of the original magma, by the consolidation of which the rock in question has been produced.

EXPLANATION OF PLATES XII. & XIII.

Plate XII.

Fig. 1. Cleveland dyke, centre: ×50. Portion of a porphyritic felspar in top right-hand corner. The remainder of the figure illustrates the general structure of the ground-mass. Crystals of felspar, grains and granular aggregates of augite, magnetite, and interstitial matter may be recognized.

2. Cleveland dyke, margin: ×50. Broken and corroded felspar in the top right-hand corner. General structure of the ground-mass shown in the remainder of the figure. Compare with fig 1.

2*a*. Armathwaite dyke: ×350. Portion of glassy base showing a small augite surrounded by longulites and globulites. Longulites formed by the coalescence of globulites. The small augite runs out into microlites.

3. Cleveland dyke, Preston: ×20. Large felspar zoned by inclusions and penetrated by inlets of the ground-mass.

4*a*. Cleveland dyke, Preston: ×170. Skeleton felspars in the ground-mass.

4*b*. Cleveland dyke, Preston: ×170. Structures observed in the interstitial matter.

5. Hett dyke, Hett village: ×40. Illustrating structure of the Hett and related dykes. Augite, felspar, and magnetite make up almost all the whole mass of the rock, and may be recognized in the figure. A patch of augite granules occurs in the centre.

6. Brunton dyke, Bingfield: ×40. Illustrating structure of the ground-mass of the Tynemouth and related dykes. The figure shows long narrow felspar sections, irregular grains and granular aggregrates of augite, and interstitial matter, rendered nearly opaque by imperfectly individualized magnetite.

PLATE XIII.

Fig. 1. Tynemouth dyke. Nicols crossed: ×20. A portion of one of the granular aggregates of anorthite is represented in the bottom right-hand portion. It is partially zoned with felspar, having different optical properties; but this zone is not continued between two contiguous grains of anorthite. Two amygdaloids occur in the top left-hand portion of the figure. The outer zone of the larger amygdaloid is formed of quartz. The ground-mass is composed of long lath-shaped felspars, bright-coloured augite grains, and dark interstitial matter, which is nearly opaque in this section, even when viewed with ordinary light. The figure illustrates the typical structure of the Tynemouth and related dykes.

Fig. 2. High-Green dyke, High Green: ×30. Ordinary light felspar, augite, and ilmenite. Structure that of a typical diabase. Brown tint of the augite somewhat exaggerated.

DISCUSSION.

The PRESIDENT remarked upon the exhaustive treatment of his subject by the Author.

Mr. TOPLEY pointed out that very little had been done by previous authors in describing these dykes. He said that in the Acklington dykes chlorophæite had been detected for the first time in England. Some of the dykes are probably of Miocene age, while of others the age is doubtful. The question of the absorption of the aqueous rocks by igneous rocks, especially basalt, is one of very great interest to geologists—the stratigraphical and chemical evidence seeming to be at variance.

The Rev. E. HILL pointed out the difference between the cases when the dyke was simply filled from below, and when the fissure formed a channel for the upward passage of the molten matter.

Mr. MARR referred to the existence of diabase dykes in Bohemia, in which fragments of Orthoceratites were found intact.

Prof. JUDD congratulated the Author on his very valuable contribution to petrographical science. He pointed out some of the difficulties in accepting the theory of the absorption of stratified material by igneous rocks.

The AUTHOR called attention to an angular fragment of sandstone included in the rock of the Cleveland dyke. It did not lend any support to the view that absorption of sedimentary rocks had taken place. He admitted that certain stratigraphical facts appeared to point to an opposite conclusion, and instanced the manner in which certain dykes terminate beneath the surface. He considered, however, that the balance of evidence at present was against the idea of absorption to any appreciable extent.